

Industrial Gas Turbine Engine Catalytic Pilot Combustor Prototype Testing

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Outline

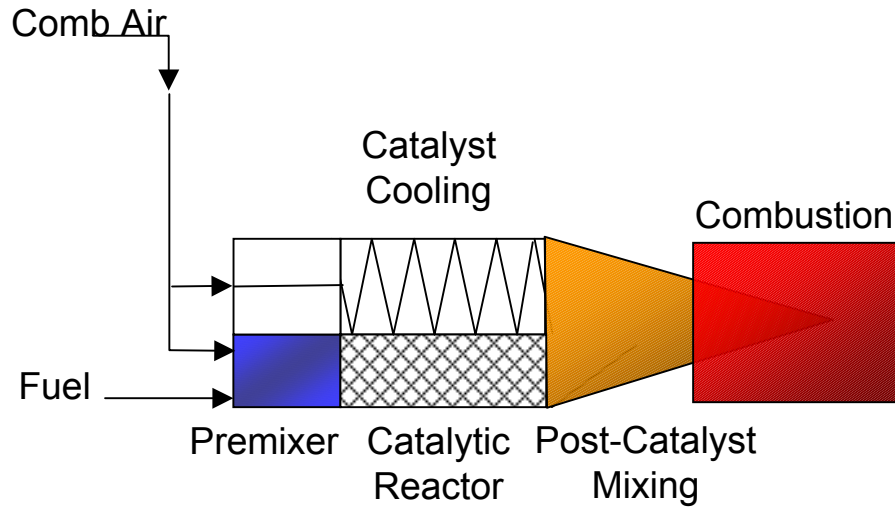
- *Catalytic pilot and RCLTM reactor concepts*
- *Catalytic pilot design and test conditions*
- *High pressure single module testing*
- *Production-ready design*
- *Reactor durability*

Objectives

- *Introduce low emission RCL™ technology to distributed energy producers (gas turbine manufacturers).*
- *Engine demonstration of RCL™ catalytic pilot technology:*
 - *NOx < 5 ppm*
 - *CO < 9 ppm*
 - *Acoustic < 0.6 psi rms*
- *Demonstrate long term catalyst durability (rig)*

Partner: Solar Turbine Inc.

Rich Catalytic Lean (RCL™) Technology

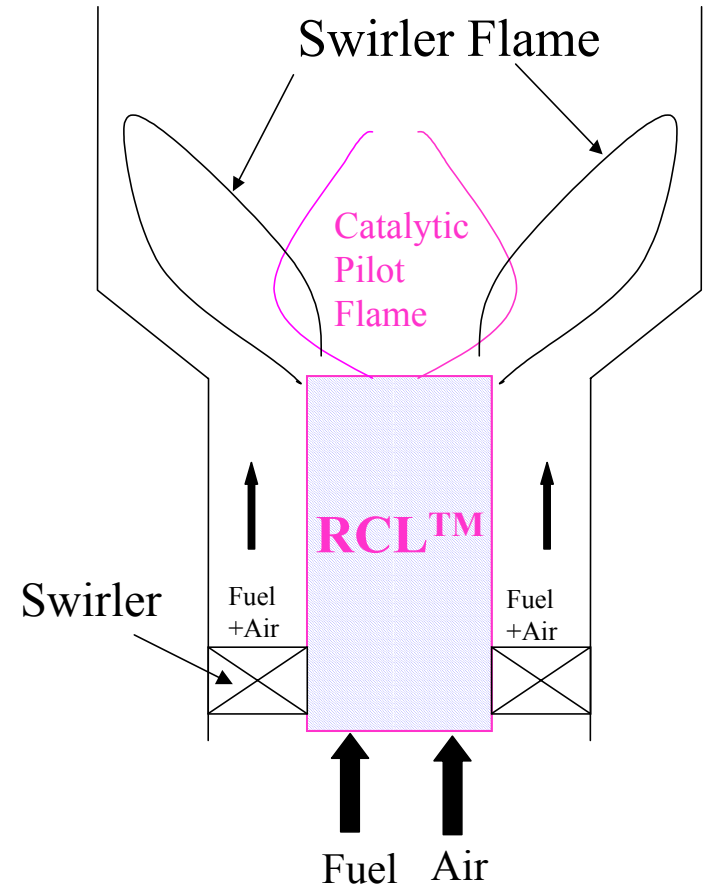


- ▶ ***Low temperature lightoff***
- ▶ ***Tolerant to fuel air unmixedness***
- ▶ ***Reduce danger of pre-ignition or flashback***
- ▶ ***Improved catalyst durability***
- ▶ ***Low combustion dynamics***

Concept for Catalytic Pilot

- **Motivation: Enable DLN gas turbines to deliver robust single digit emissions with minimal modification / retrofit**

- **Catalytic pilot replaces diffusion flame/partial premixed pilot**
- **Catalytic reaction provides stability to the pilot flame, which in turn provides stability to swirler flame**
- **Catalytic reactor based on Rich Catalytic Lean (RCL™) combustion approach**



Single Injector Catalytic Pilot



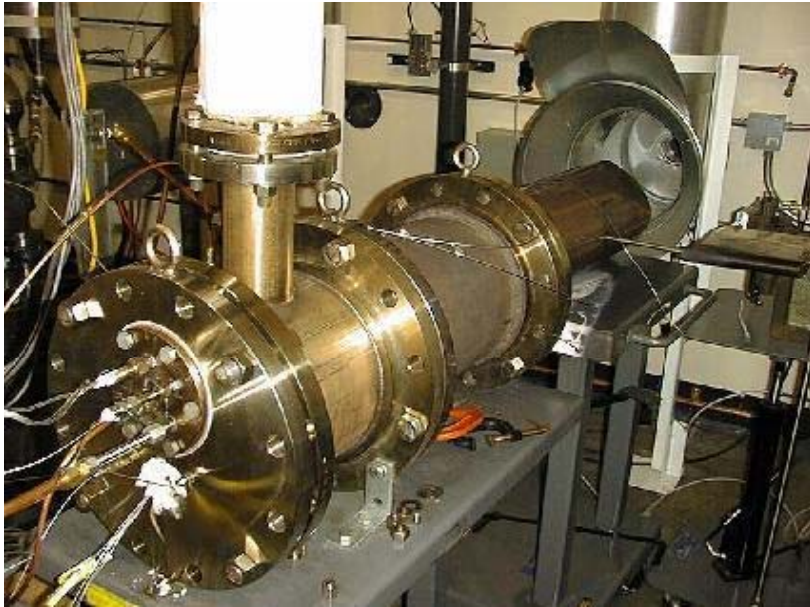
Catalytic pilot installed within a Taurus 70 (T70) swirler hub

- ***Minimum modification to the swirler hub is required***
- ***Catalytic pilot fits within the existing physical envelope***

Load Conditions for Taurus 70 Engine

Baseload Inlet Temperature	705 K (432°C/810 °F)
Baseload Inlet Pressure	1.7 Mpa (250 psia)
Baseload Pressure Drop	4.0%
Half-load Inlet Temperature	636 K (363°C/ 687 °F)
Half-load Inlet Pressure	1.02 Mpa (153 psia)
Half-load Pressure Drop	3.5%

Test Rigs



Atmospheric pressure rig @PCI



High pressure rig @ Solar Turbines

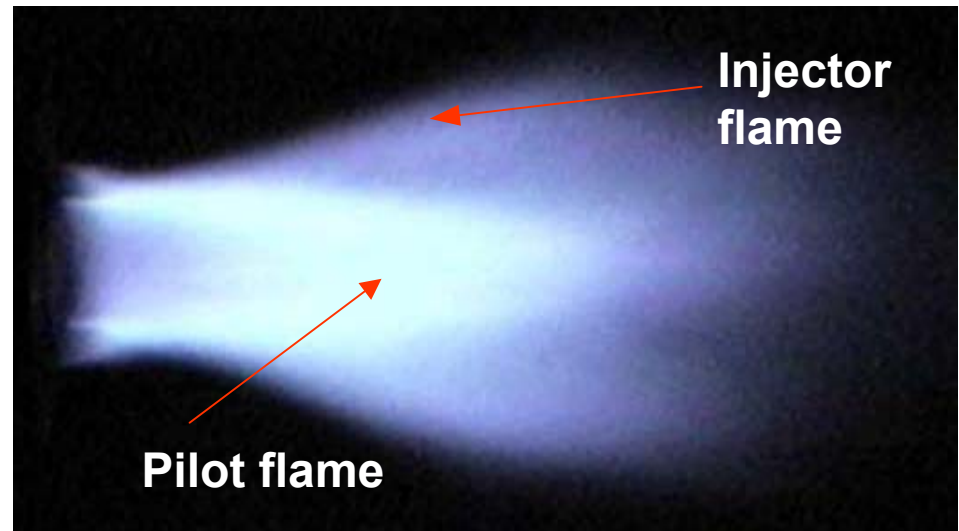
- ***Catalytic pilot was tested both at PCI and Solar Turbines***

Atmospheric Operation of Catalytic Pilot

Front View



Side View

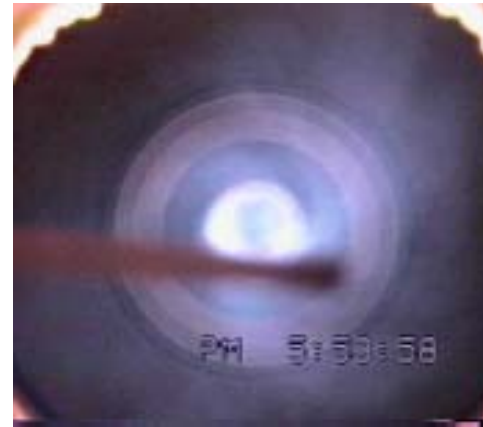


- *Stable pilot and injector flame for a range of conditions.*
- *Pilot flame provides stability to the lean injector flame.*

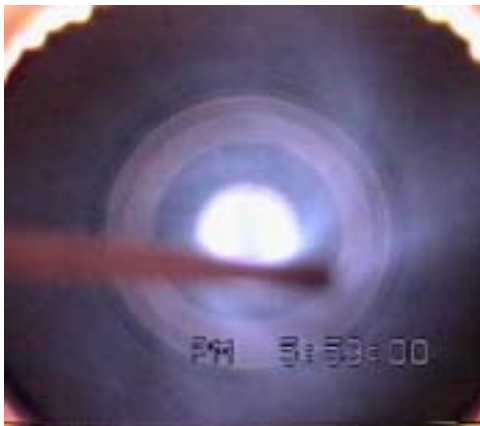
Atmospheric Operation of Catalytic Pilot



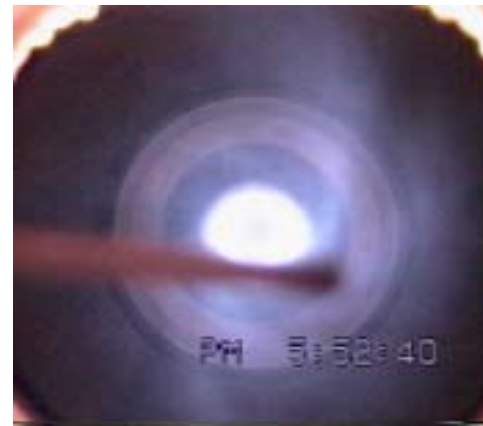
Pilot $\phi = 0.5$, Swirler $\phi = 0.45$



Pilot $\phi = 0.5$, Swirler $\phi = 0.5$



Pilot $\phi = 0.6$, Swirler $\phi = 0.5$



Pilot $\phi = 0.7$, Swirler $\phi = 0.5$

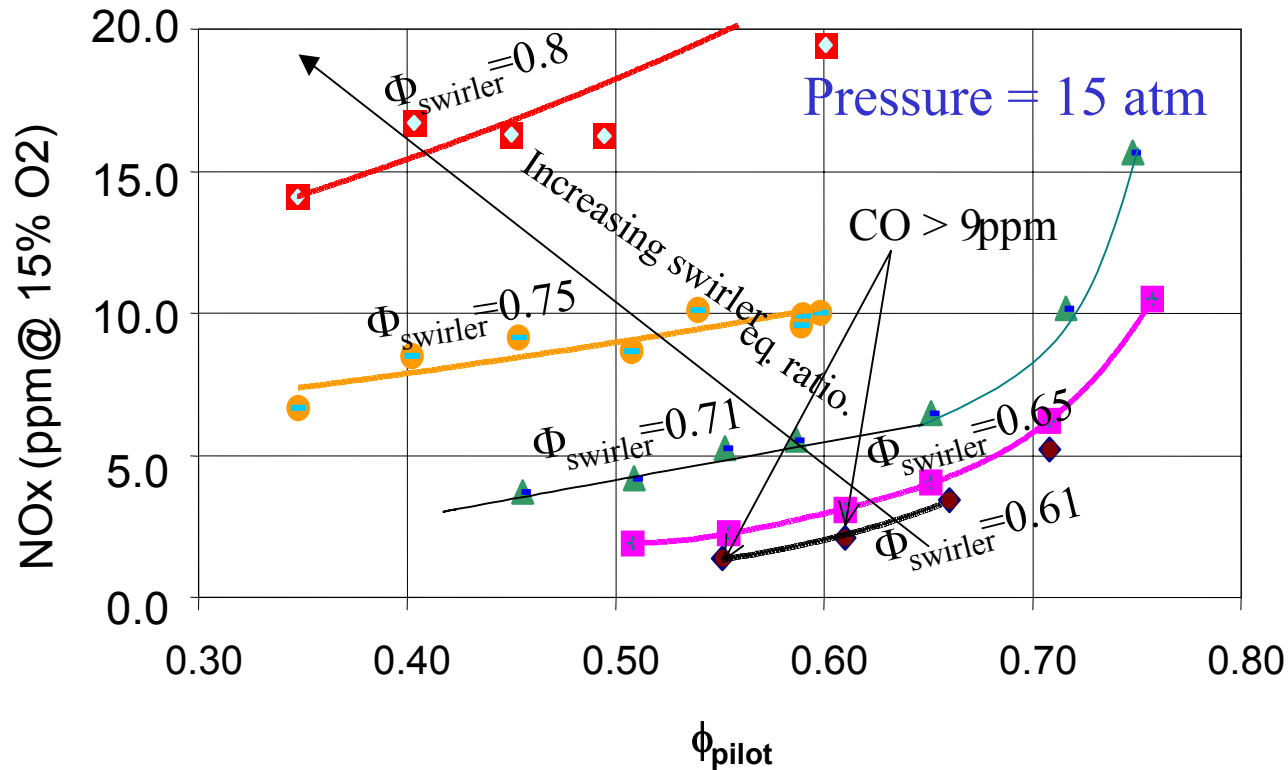
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Stable flame for a range of pilot and swirler equivalence ratios

PCI

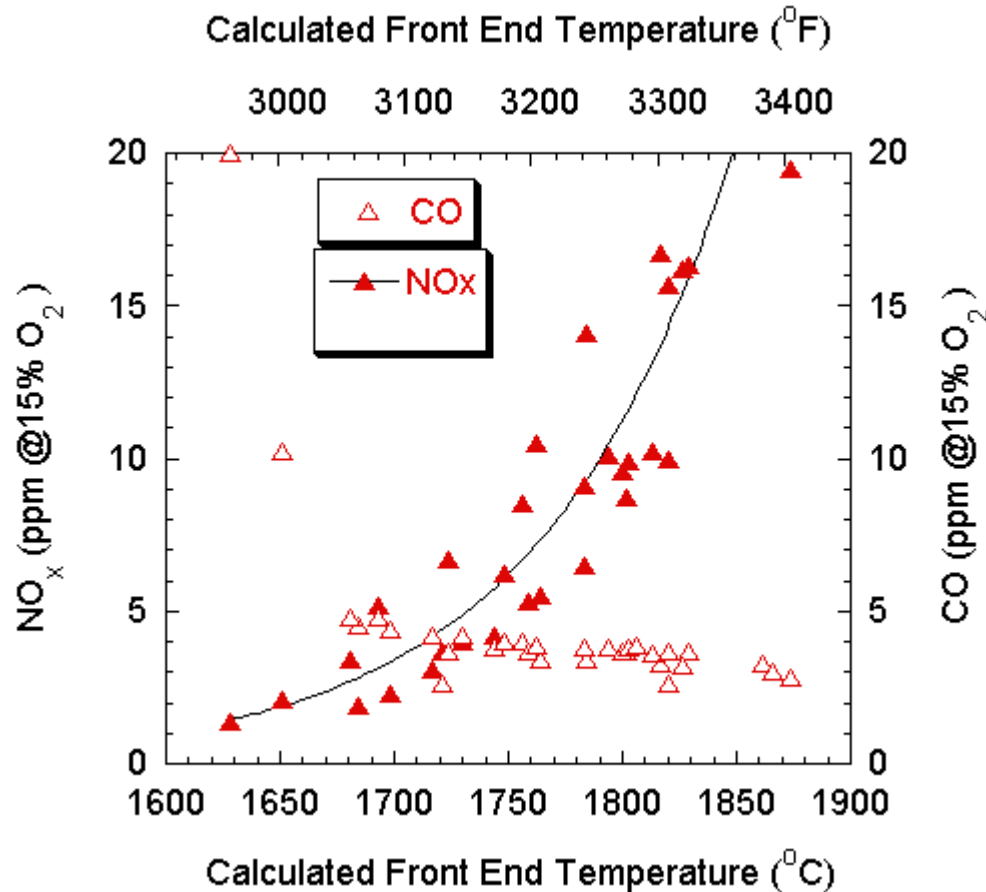
Precision Combustion, Inc.

Emissions Data @ 15 atm. and ΔP of 4.5%



- **Stable flame for a range of pilot and swirler equivalence ratio**
- **Low CO and NOx emissions**

Emissions Data @ Solar High Pressure



P= 15 atm

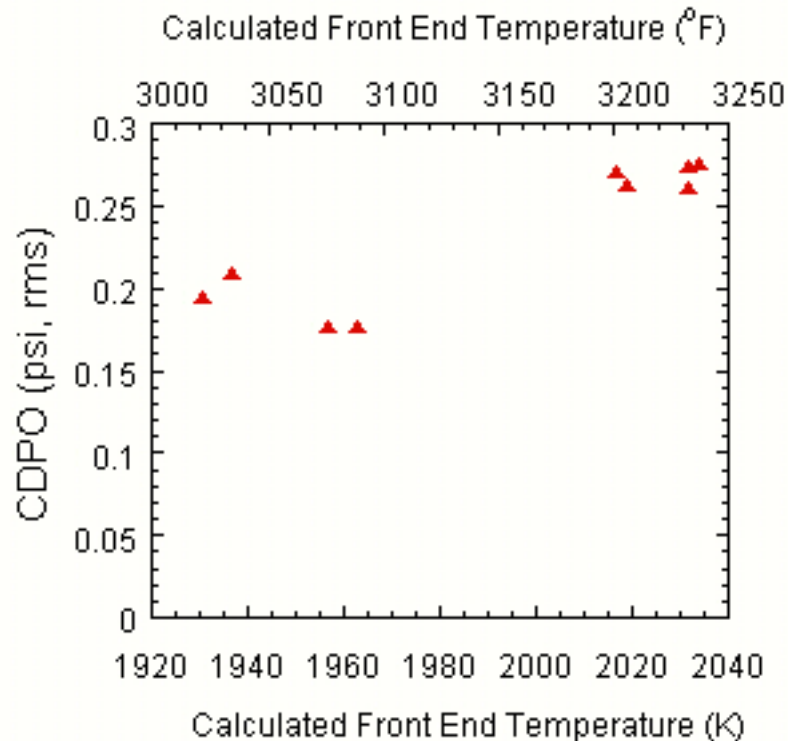
dp = 4.5%

- ***Single digit emissions***
- ***Wide operating window***

PCI

Precision Combustion, Inc.

Acoustics Data @ Solar High Pressure



P= 15 atm

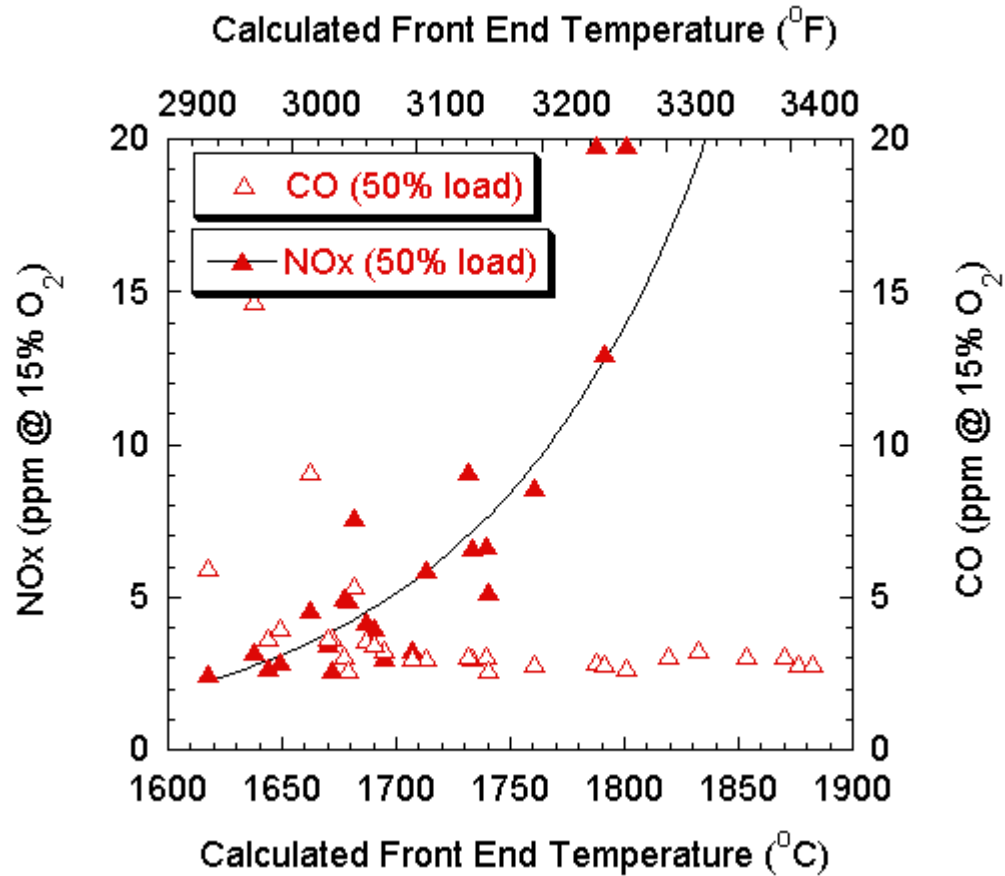
dp = 4.5%

- ***Low Dynamics < 0.3 psi (rms) in baseload operating window***

PCI

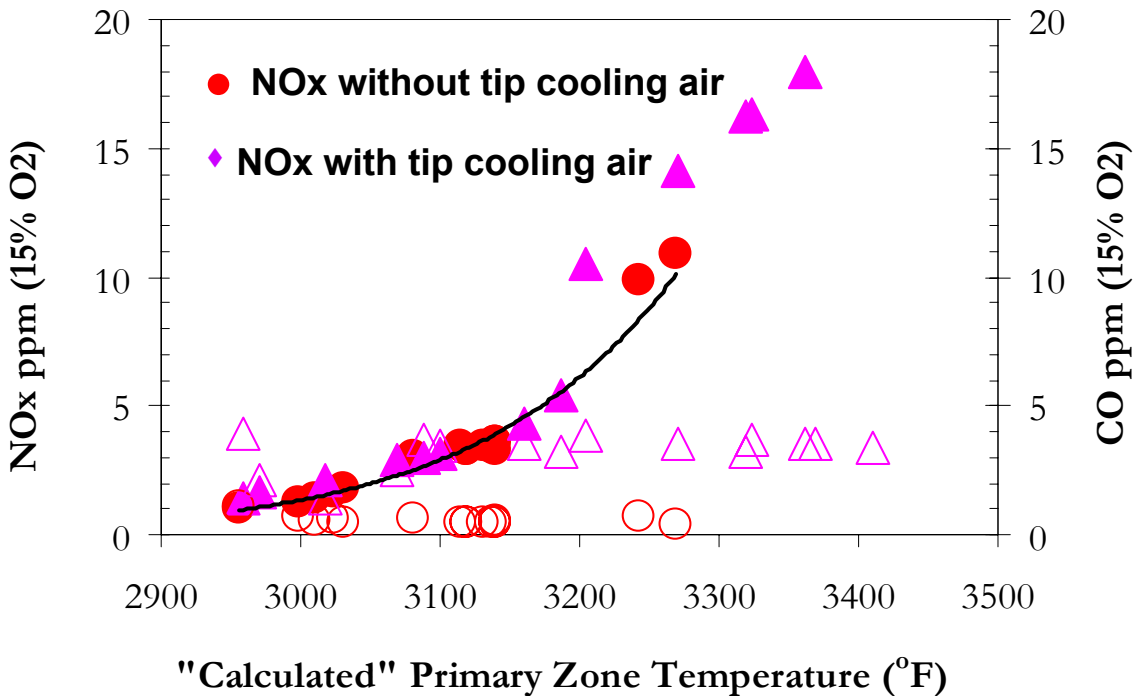
Precision Combustion, Inc.

Emissions Data @ of 50% Load



- ***Single digit emission are achievable @ 50% load***

Emissions with and without tip cooling



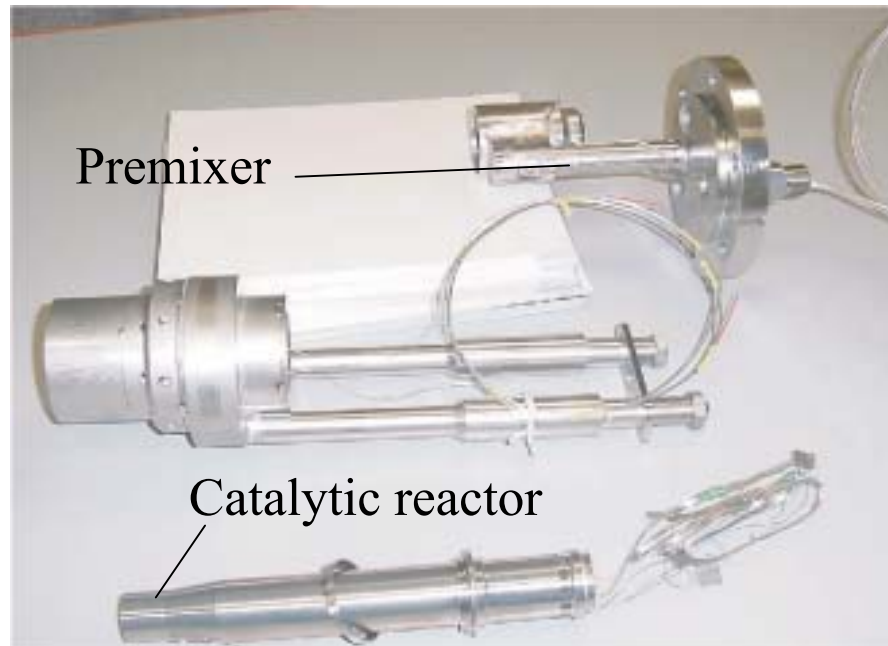
Pilot tip

• No effect of tip cooling air on emissions

Single Injector High Pressure Rig Testing Summary

- *Robust operation demonstrated with wide range of pilot fuel/air ratios*
- *No pre-burner required*
- *Ultra low single digit NO_x and CO from 50-100% load*
- *No pressure drop impact*
- *Ideal for retrofit application, low cost*

Modular Catalytic Pilot

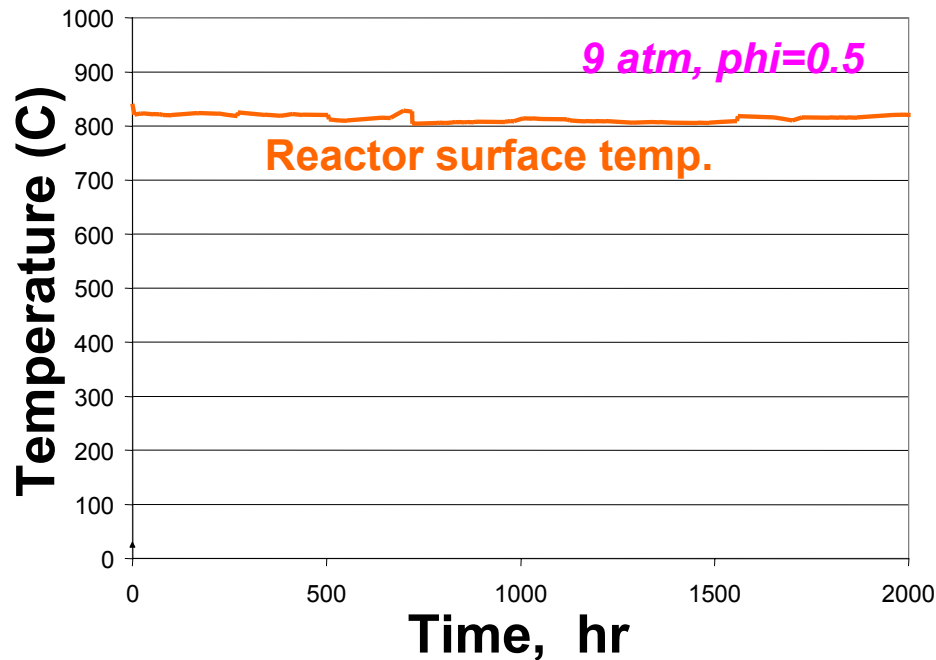


- *Production-ready (modular) design of catalytic pilot complete*
- *1st prototype fabricated*
- *Catalytic reactor can easily be replaced in the field*

Catalytic Pilot: Current Status

- *Pilot tip cooling issue resolved with no degradation in performance*
- *Production-ready design completed*
- *Structural analysis of the catalytic reactor completed*
- *Completed fabrication of the 1st prototype based on the production-ready design*

RCL Durability



- ***2000 hour durability test successfully completed***
- ***No measurable performance degradation - moderate temp, fuel-rich environment over catalyst***
- ***Initiating 4000 hour durability test***
- ***8000 hours durability predicted for market entry. Targeting 25000 hour life starting 2006***

Milestones Planned

- *Single injector rig test for engine ready prototype - Dec 2003*
- *Fabricate engine set (12 injectors) - March 2004*
- *Test 3-4 Catalytic Pilots from the engine set in Solar high pressure-rig - Apr. 2004*
- *Atmospheric engine rig assembly and test - May 2004.*
- *Completion of 4000 hours durability rig testing - May 2004*
- *Engine test at Solar - June 2004*

Project Accomplishments

- *Excellent operability (start-up, part-load and base load) demonstrated.*
- *Low single digit NOx demonstrated from 50-100% load*
- *Completed production-ready design of catalytic pilot*
- *Prototype based on new design fabricated*
- *2000 hours catalyst durability completed, 8000 hours durability predicted for market entry. Targeting 25000 hour life starting 2006*